





SimCenterTools and Capabilities for Experimental Researchers

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Acknowledgments

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SimCenter's Mandate

Advance the Nation's capability to **simulate the impact** of natural hazard events on structures, lifelines, and communities.

Create an open-source and extensible application framework, integrate existing tools and data, and develop new software to provide the **next-generation of regional disaster simulation tools**

Support researchers and practitioners with **education and training**, and connect them with high-performance computing resources.



Unifying Simulation Platform



Performance-Based Engineering





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SimCenter Application Framework



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pre-

post-

Unifying Simulation Platform



Example Workflows – Earthquake Risk





Desktop Applications



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Desktop Applications



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R2D – Regional Simulation



Create and run complex workflows for regional simulation of natural hazards to facilitate research in disaster risk management and recovery.

Asset definition

CSV and GIS files

Hazard definition

Regional Site Response Custom earthquake and hurricane grids Earthquake, hurricane, tsunami rasters Earthquake, hurricane event simulation

Response, Damage and loss

FEM simulations of response HAZUS and other fragility models User-provided fragility functions



Multiple Hazard Types



Earthquakes

Multiple Asset Types







Buildings

Lifelines

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PBE – Performance Assessment



Integrates UQ applications of quoFEM, Building Model Generators, Earthquake Loading, analysis engine and our PELICUN tool for damage and loss assessment.

Damage & Loss (using PELICUN):

Building-level assessment (e.g., HAZUS) Component-level assessment (e.g., FEMA P58) Supports external response estimation Customizable fragility & consequence functions



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EE-UQ – Earthquake Engineering



EE-UQ V3.0

- Earthquake Simulation of Buildings and Site Effects
- Automatic model generators and surrogate model development

Hazard (Earthquake):

Target Spectrum (OpenSHA, OpenQuake) Ground Motion Selection/Scaling (PEER NGA) Stochastic Motions Site Response with Random Fields

Structural Modeling:

Detailed FE Models (OpenSees) Simplified Nonlinear Model Auto Steel and RC Building Design

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quoFEM – Calibration



Integrates Simulation Applications with UQ Applications

UQ Problem Types

Sampling Sensitivity Reliability Calibration Bayesian Calibration Surrogate Modeling

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Broadening Impact

The SimCenter ecosystem facilitates collaboration and accelerates dissemination of new ideas.

Examples:

- 40 tall steel building models published in DesignSafe soon
- Automatic model generator for steel and RC frames (AutoSDA & RC-FIAP)
- Idealized shear column model for buildings (MDOF-LU)



Enhancing Intellectual Merit

Leverage advanced methods developed in the community

Examples:

- Complex, hazard-consistent ground motion record selection
- Surrogate modeling techniques for structural response estimation
- Performance assessment methods to estimate damage & losses
- Sang-ri shows additional examples later





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Multi-Disciplinary Collaboration





Trainings & Resources

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 may z 	1, 2021, 12	E3 - OpenSeess E5 - Ground Shi See the Tool's Docume The current version all earthquake events. The event, and future versic contact NHERI-SimCer	Seathdus ABOUT 1. Albout 1. Actionaledgenets 2. Copyright and Lemne 2. Gossary 3. Abbreviations	The R2D app, as will be discuss applications to run in a workfit The main window of the U is o	seed in Software Architecture, is a self- dication. Once the R2D app is started ow, inputs the necessary parameters for divided into several separate areas: Nutrue basedon her	tile worklow application that c the user is presented with the u- r each of these applications, standard the u- Me	reates workflows and runs them is the bar were interface above in Fig. 2.3. Is its in this rts the workflow either locally or remotely ssage Area	ckground. These workflox kUI where the user select and finally views the sir
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			2.6. MOD: Asset Modeling 2.7. ANA: Asset Analysis 2.8. DL: Damage and Loss 2.9. UQ: Uncertainty Quantification	Push Buttons	-			

SimCenter Website

- Software & Documentation
- Upcoming Education & Training Events
- Forum & Other Communication
- Visiting Researcher Position
- REU Positions

https://simcenter.designsafe-ci.org/

About quoFEM

Quantified Uncertainty and Optimization for the Finite Element Method (quoFEM)



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Benefits – SimCenter Tools for Experimental Researchers

QUOTEM: Qua	antified Uncertainty with Optimizal	tion for the Finite Element Method			
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- 1. Moderate-to-high dimension
- 2. Efficient algorithms for expensive models
- 3. Advanced Calibration and UQ techniques
 - Model class selection
 - Hierarchical Bayesian
 - Surrogate-enabled calibration

Easy-to-use user interface

pset P 25

pset Au 500

pset Ao 250

Link with the DesignSafe HPC

Accelerated and advanced algorithms

set Au 500 set Ao 250

Inside quoFEM



UQ Algorithms

- Latin Hypercube Sampling/Monte Carlo
- Gaussian Process Regression
- Polynomial Chaos Expansion
- Probability model-based GSA (PSA)
- Principal component analysisbased PSA
- Smart Monte Carlo Method
- Local Reliability (FORM, SORM, etc.)
- Global Reliability
- Importance Sampling
- OPT++GaussNewton
- NL2SOL
- Gradient-free
- Transitional Markov Chain Monte Carlo
- Differential Evolution Adaptive Metropolis
- Gaussian Process (GP) Surrogate Modeling
- Adaptive Design of Experiments
- Non-homogeneous GP modeling
- Multi-fidelity GP Modeling
- Probabilistic Learning on Manifold PLoM
- User-provided Algorithms

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Examples





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Ex1. Constitutive soil model calib.



Adithya Nair 2021 summer REU from the Ohio State University

Currently grad, student at UC Berkeley

- To calibrate liquefaction capable soil material model (PM4Sand) (Boulanger and Ziotopoulou, 2017)
- Experimental output Number of cycles to onset of liquefaction at given cyclic stress ratios (CSR)



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Inside quoFEM

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Global Sensitivity Analysis

- What are the important parameters?
- Method: Probabilistic model based global sensitivity analysis (Hu and Mahadevan 2019)

Computational model Material: PM4Sand v3 Element: SSPquad (4 node) D_r : relative density G_0 : shear modulus coefficient h_{po} : contraction rate parameter **MopenSees** Opensees Script EMaterial PM4Sand element SSPquad "PlaneStrain' constraints Transformation NormDispIncr 1.0e-5 35 1 algorithm Newton umberer RCM ntegrator Newmark [expr 5.0 / 6.0] [expr 4.0 / 9.0] solidation pr et pNode [expr Ssigvo / 2.0] pattern Plain 1 (Series -time (0 100 1e10) -values (0 1 1) -factor 1) (load 4 pdateMaterialStage -material 1 -stage set ts1 "{Series -time (100 80000 1.0e10} -values {1.0 1.0 1.0} -factor 1}" eval "pattern Plain 2 \$ts1 { sp 3 2 \$vDisp sp 4 2 \$vDisp



Sensitivity indices





Nair AS et al. (2021), Research Experience for Undergraduates (REU), Uncertainty Analysis of Seismic Soil Liquefaction using quoFEM. DesignSafe-CI. Yi, S. et al (2022), Sensitivity analysis and Bayesian calibration of a constitutive soil model using quoFEM, OpenSees Days 2022 Eurasia, July 7-8, Turin, Italy

Bayesian Parameter Calibration

What are the parameter values?

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Method: Transitional Markov Chain Monte Carlo (Ching and Chen, 2007)



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Calibrated output

Mean prediction Experimental data

95% Confidence bounds

95% Prediction bounds (for noisy observations)

Forward Uncertainty Propagation

- Random variables: Dr, G_o, h_{po}
- Output: Vertical profile of horizontal displacement of the soil column

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Predictive mean

Random realizations

Ex2. Calibration of RC wall properties (Stokley and Lowes, 2022)

-3

-2 -1

Calibrating material model parameters using "structural" response

Experimental data



Cyclic load test data on 142 reinforced concrete walls (Shegay et al. 2021)

Computational model



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parameter

Challenges.

- 1. Computationally expensive model
- 2. Gradient-based algorithms not applicable

Parameters of interest

Concrete crushing energy (Gfcc/Gfuc) → Concrete compression failure

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Drift %

Steel rupture strain reduction factor (SRS) → Rebar rupture

Inside quoFEM

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Ex2. Calibration of RC wall properties (Stokley and Lowes, 2022)

Experimental data



DESIGNSAFE-CI

Data Depot Project 2430 (Shegay et al. 2021)

142 walls from 32 research programs mostly rectangular walls tested under cyclic protocols in 1960-2010s



Failure Mode CB **Compression Buckling**



Compression - buckling failure (Dazio et al. 2009)

Failure Mode BR **Bar Rupture**



Tension failure (Dazio et al. 2009)

Failure Mode CS **Compression Shear**

Simulated concrete

Ex2. Calibration of RC wall properties (Stokley and Lowes, 2022)

Computational model



Multi-layer shell element (ShellMITC4)

Parameters of interest

- **Concrete** crushing energy (Gfcc/Gfuc)
 - crushing failure mode
- Steel rupture strain reduction factor (SRS)
 - bar fracture failure mode









Compression Shear



SimCenter WERI Stokley, J., Lowes, I through opensees a

Stokley, J., Lowes, L., 2022, Modeling reinforced concrete walls with shell elements to simulate through opensees and using jupyter to post process results, Design-Safe Jupyter notebook



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Ex3. Reduced Order Modeling



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Ex3. Reduced Order Modeling



Patsialis, D., A. A. Taflanidis, and D. Vamvatsikos. "Improving the computational efficiency of seismic building-performance assessment through reduced order modeling and multi-fidelity Monte Carlo techniques." Bulletin of Earthquake Engineering (2022): 1-37.



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Ex3. Reduced Order Modeling

Three ground motions used for training

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Seismic Risk Assessment

Using the reduced model and 200 artificial ground motions



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generate **200 ground motions** M = 7.5 and R = 20 km $V_{s30} = 600$ m/s (Vlachos et al, 20 18)



Benefits – SimCenter Tools for Experimental Researchers

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pset Au 500

pset Ao 250

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set Au 500 set Ao 250

Summary – SimCenter Tools for Experimental Researchers

..... and broader impact through SimCenter ecosystem



Regional-scale response prediction

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